Modeling contamination migration on the Chandra X-ray Observatory — IV

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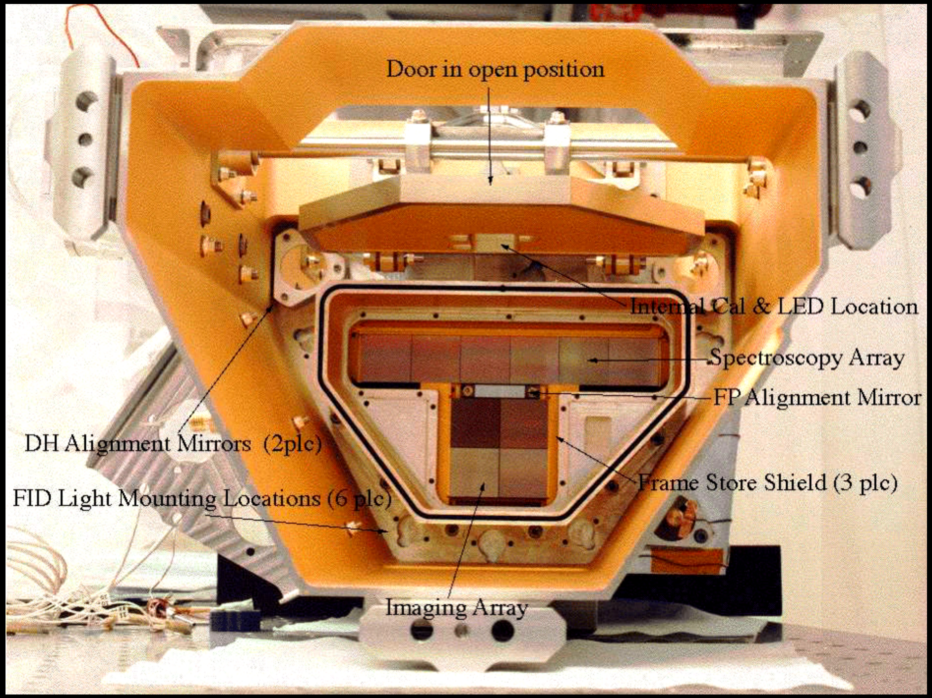
Outline

- Introduction
- Molecular contamination on ACIS filters
- Thermal model for ACIS cavity
- Molecular transport simulations
- Summary

Chandra's Advanced CCD Imaging Spectrometer (ACIS)

- ACIS cavity
  - Collimator
  - Snoot & door
  - Camera top & filters (OBF)

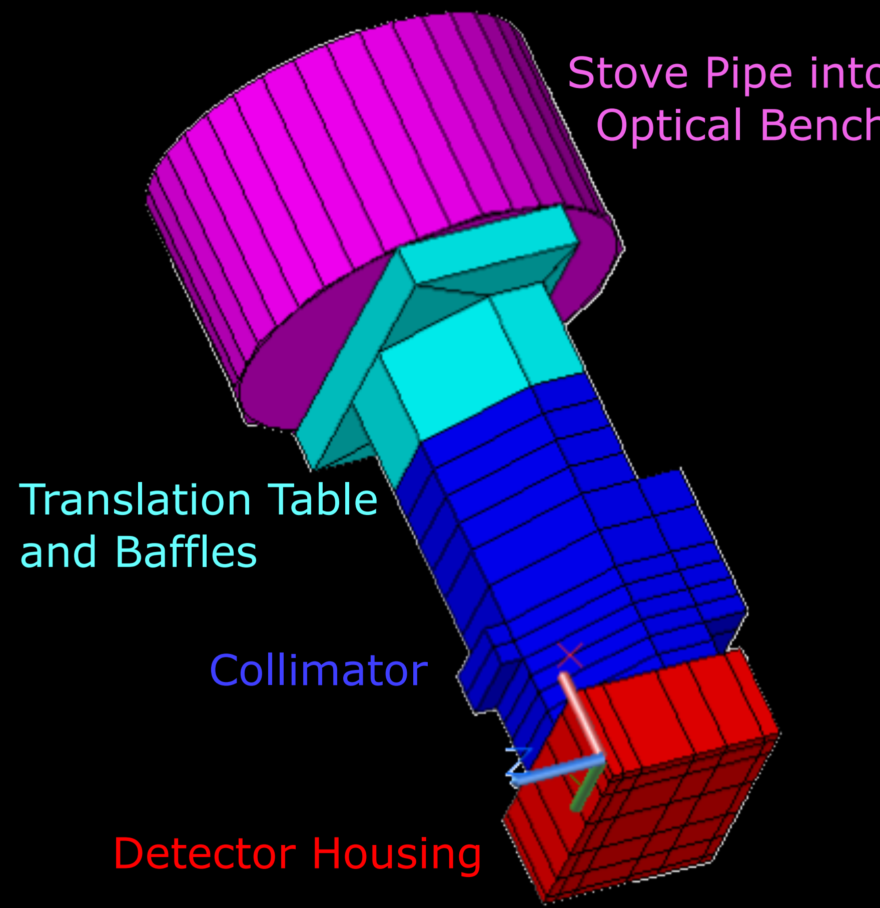


- ACIS operating temperatures
  - Focal plane T_{FP}=-120°C
  - Camera housing T_{DH}=-60°C
    - ≈6°C colder with heaters off
  - Optical blocking filters T_{OBF}
    - $\approx T_{DH} \approx$-60°C near OBF edge
    - 5–20°C warmer near center
- Contamination on cold OBFs
  - Mass column ≈ 200 μg cm^{-2}
    - ≈ 50 × pre-flight estimates
    - ≤ 1 g in entire *Chandra* optical cavity (calculated)
  - Thicker near OBF edge
  - Doubled during 2013–2017

Contamination-migration simulations for Chandra

- 2005 (I)
  - Low-resolution geometric model for ACIS cavity
- 2013 (II)
  - High-resolution geometric model for ACIS cavity
  - Higher emissivity for contaminated surfaces
- 2015 (III)
  - Same model as 2013
- 2017 (IV)
  - Extend geometric model into optical bench

- Geometric model (exterior)



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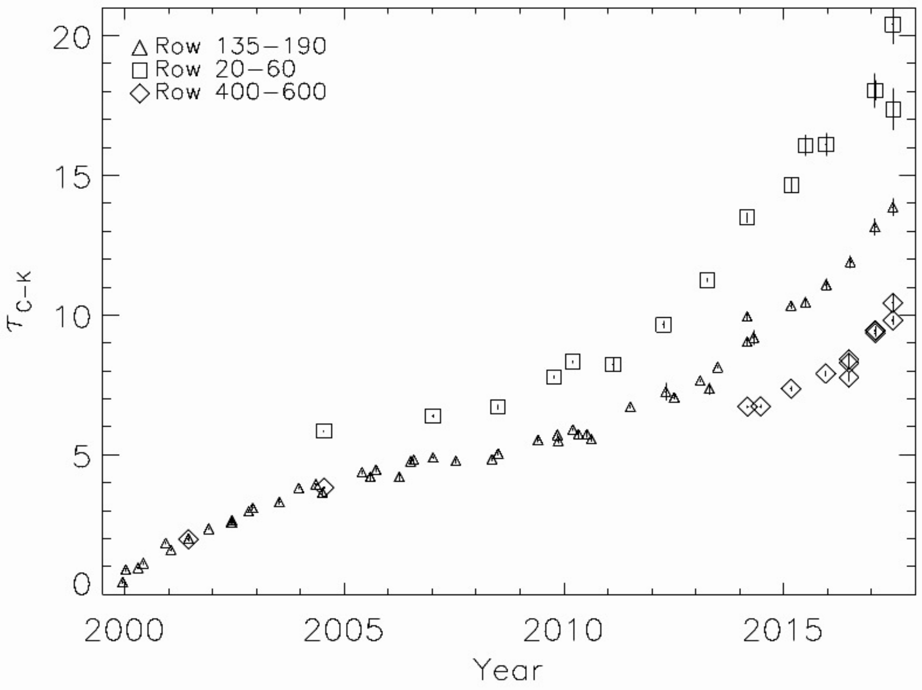
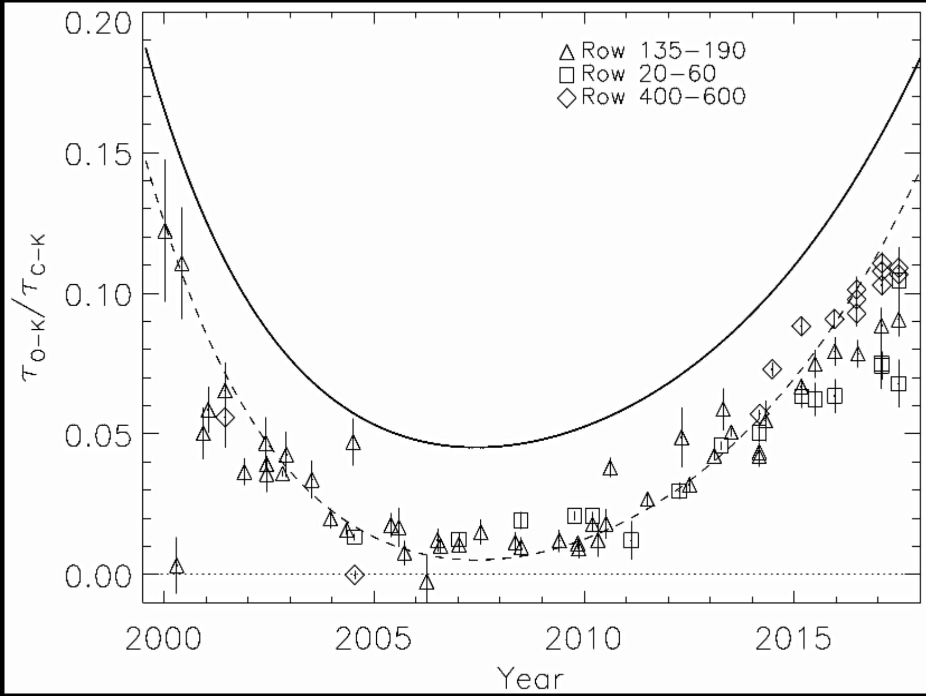
Evolution of mass column, its rate, and composition

- Accumulation of contaminants
  - LETG/ACIS-S spectra
    - Atomic (C,O,F) edge depths
  - Thickest near OBF edges
  - Rate fell until about 2008 then started rising
  - Multiple species

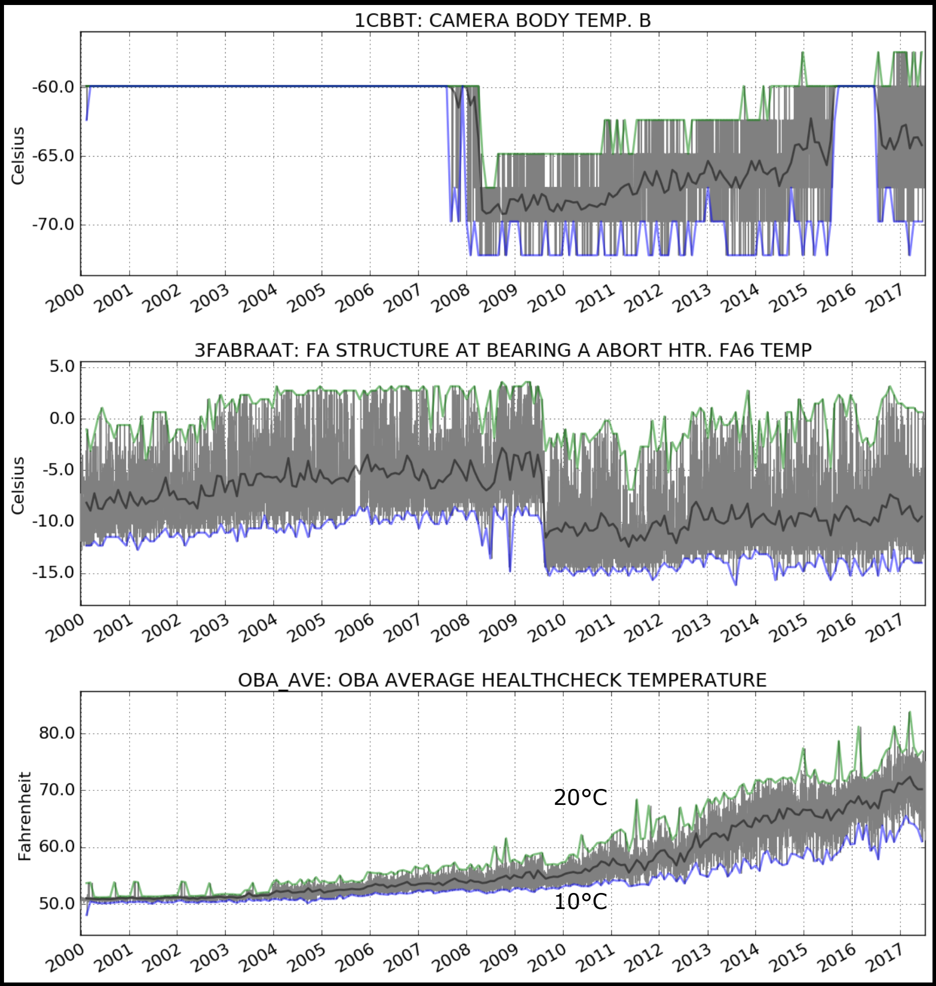
See next presentation by Herman Marshall





Thermal history

- Most systems are warming
  - Continuing degradation of external insulation (MLI)
- Strive to keep ACIS focal plane cold to preserve performance
  - Carefully plan observations
  - Disabled some heaters
    - ACIS detector-housing heater (2008 April)
    - A SIM focus-assembly heater (2009 August)
- Optical Bench has warmed rapidly since about 2010
  - New contamination source?



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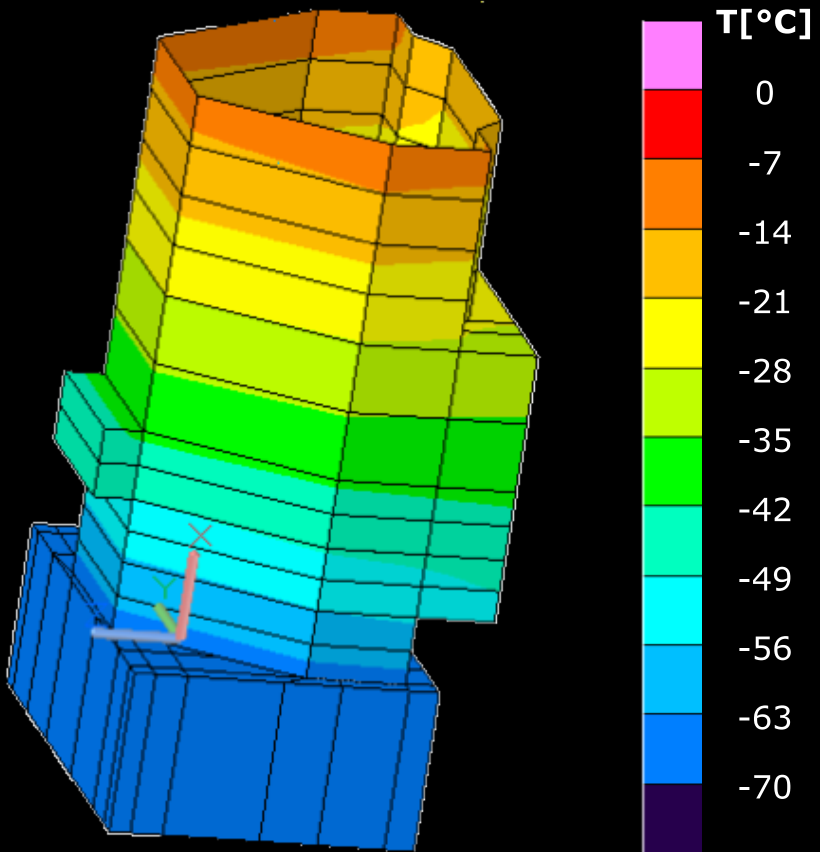
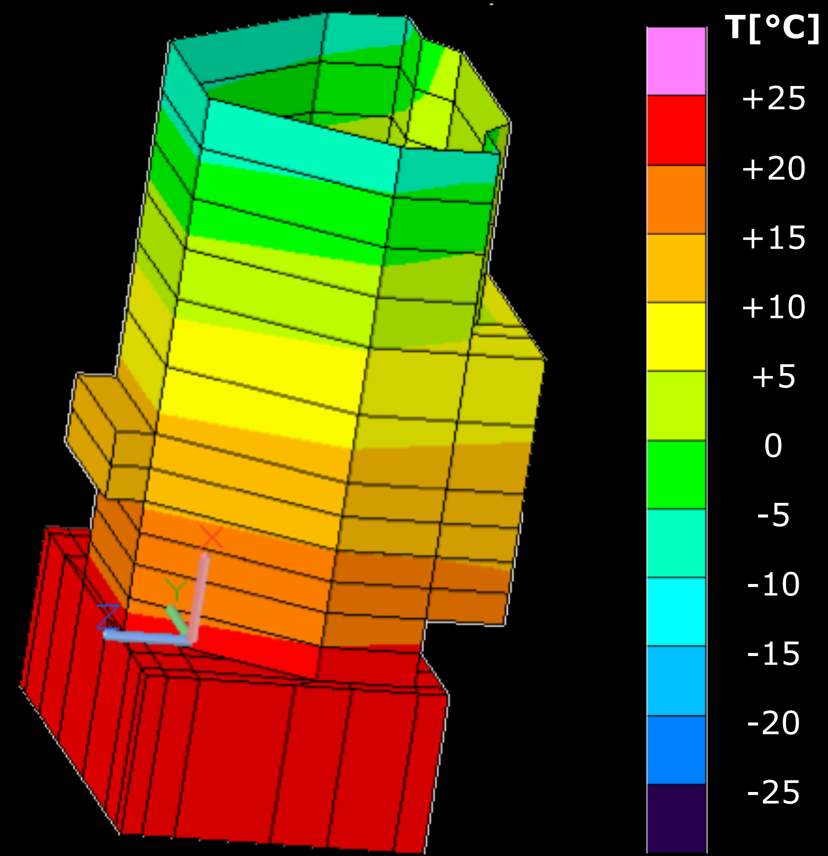
ACIS temperature distribution (exterior)

- DH heater OFF, T_{FP} = -120°C
- T_{DH} = +25°C, T_{FP} = -60°C



ε_{OBF} = 0.40



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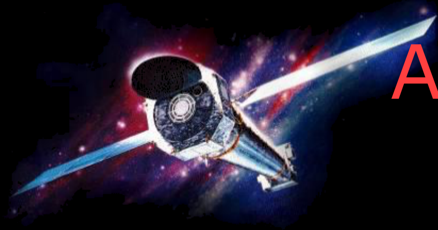
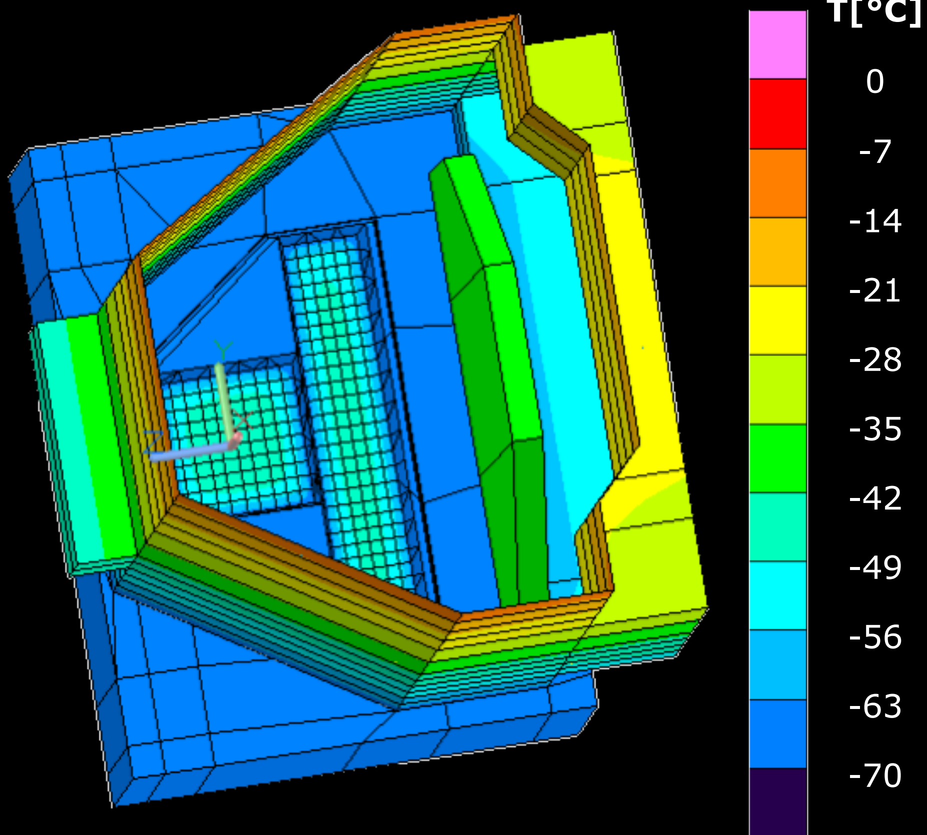
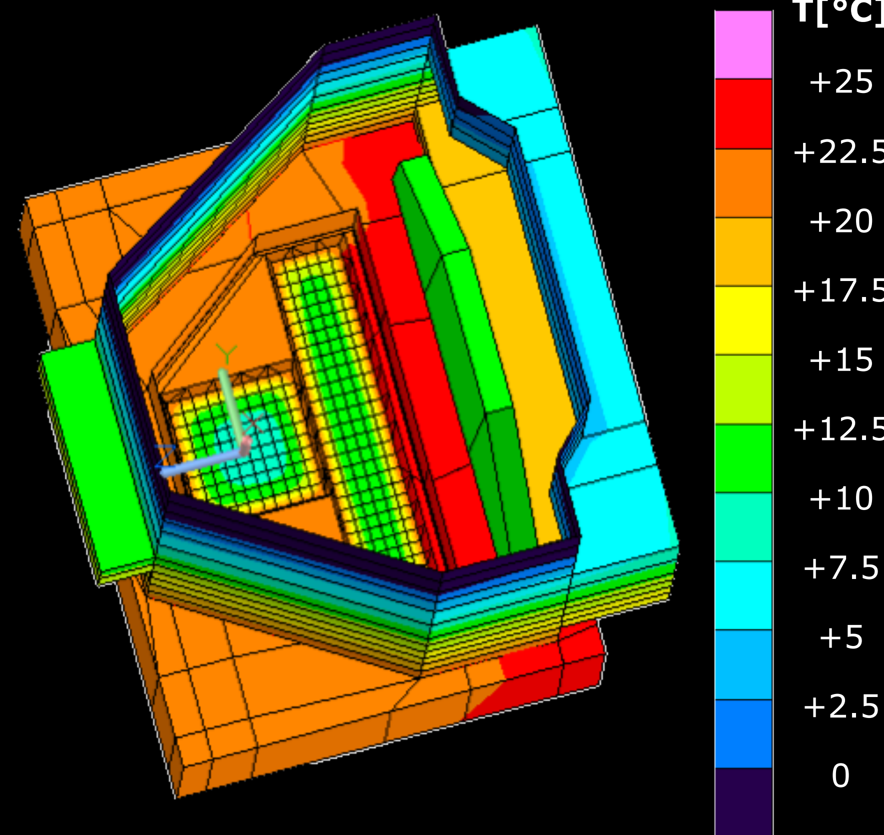


ACIS temperature distribution (interior)

- DH heater OFF, T_{FP} = -120°C
- T_{DH} = +25°C, T_{FP} = -60°C



ε_{OBF} = 0.40



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Molecular flux equations and geometric view factors

- Net mass flux onto node j

$$\frac{d\mu_j}{dt} = -\dot{\mu}_v(T_j)\Theta(\mu_j) + \sum_k \dot{\mu}_v(T_k)\Theta(\mu_k)\, f_{jk}\,\frac{A_k}{A_j}$$

- Mass vaporization flux
  - Related to vapor pressure

$$\dot{\mu}_v(T) = \frac{P_v(T)}{\sqrt{2\pi\, RT/M}}$$

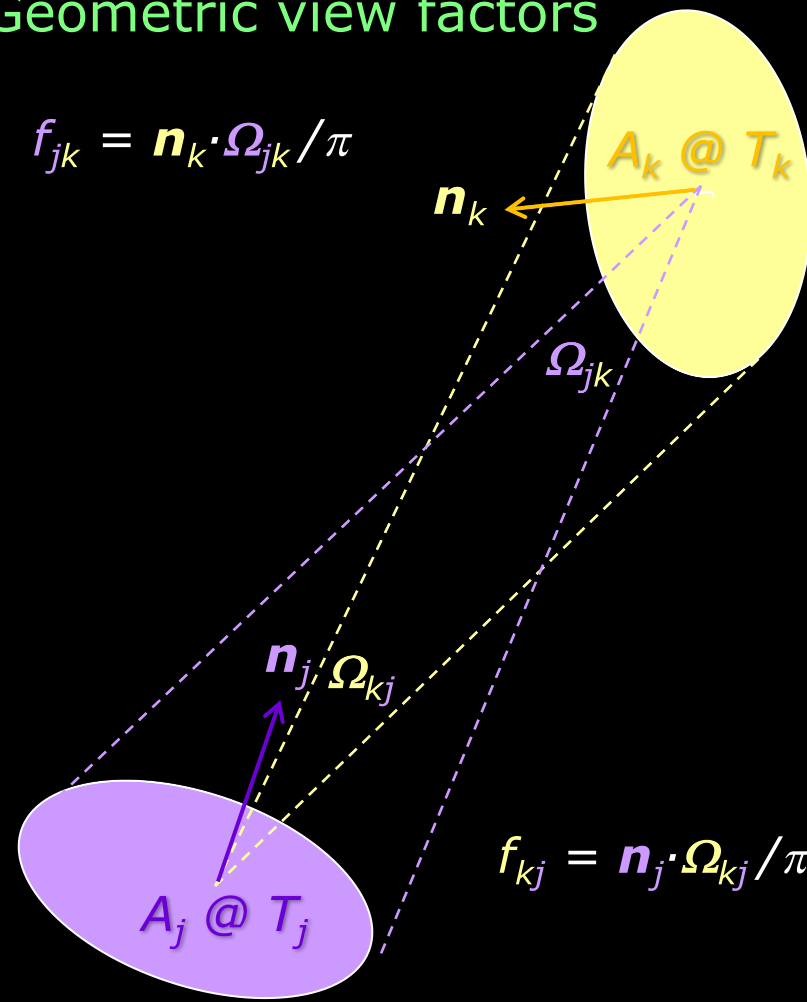
- Clausius–Clapeyron relation
  - Temperature dependence
  - Vaporization enthalpy $\Delta_v H$

$$P_v(T) = P_v(T_\circ)\,\mathrm{Exp}\left[-\frac{\Delta_v H}{R}\left(\frac{1}{T} - \frac{1}{T_\circ}\right)\right]$$

$$\dot{\mu}_v(T) = \dot{\mu}_v(T_\circ)\sqrt{\frac{T_\circ}{T}}\;\mathrm{Exp}\left[-\frac{\Delta_v H}{R}\left(\frac{1}{T} - \frac{1}{T_\circ}\right)\right]$$

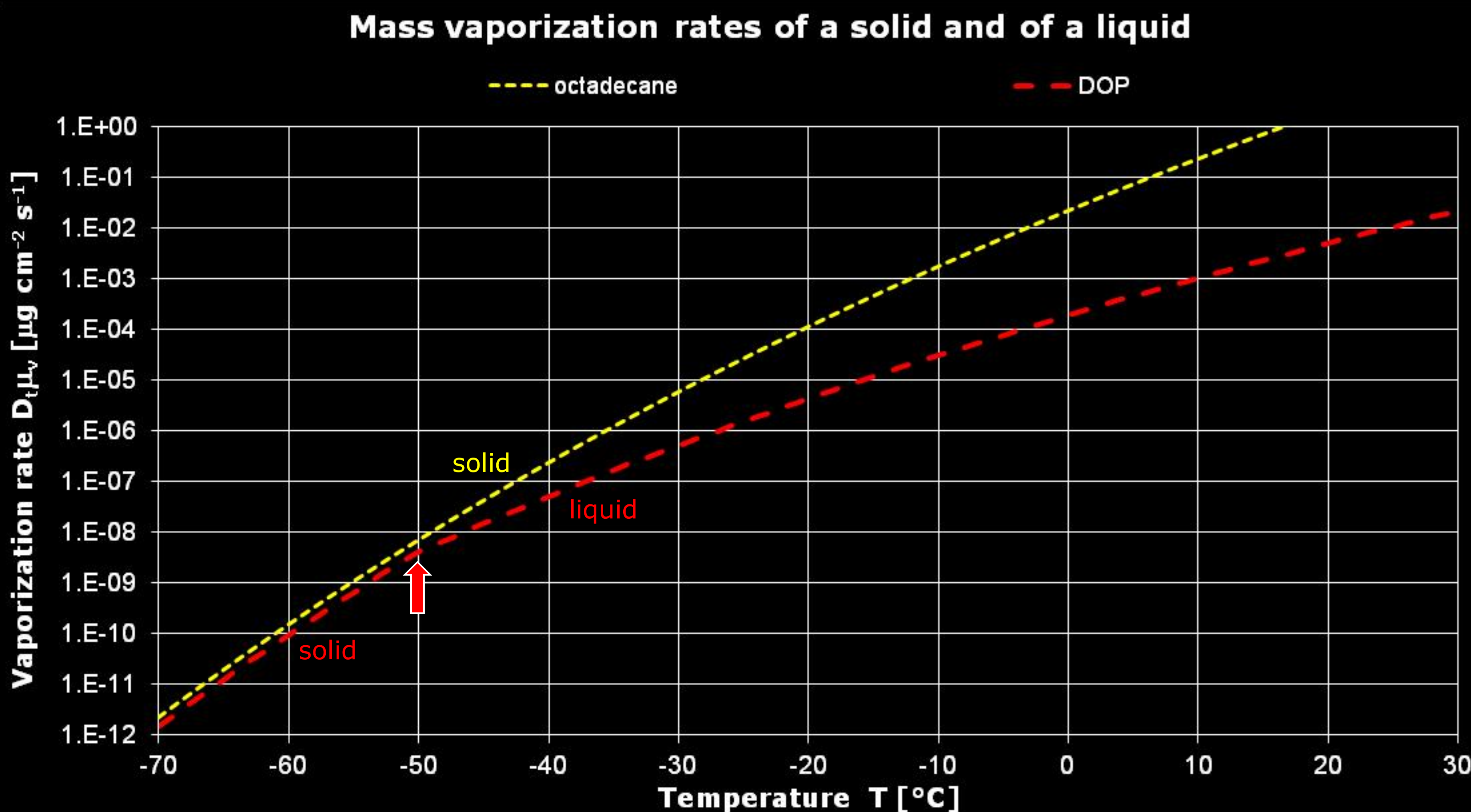
- Geometric view factors

$$f_{jk} = \boldsymbol{n}_k \cdot \Omega_{jk} / \pi$$



$$f_{kj} = \boldsymbol{n}_j \cdot \Omega_{kj} / \pi$$

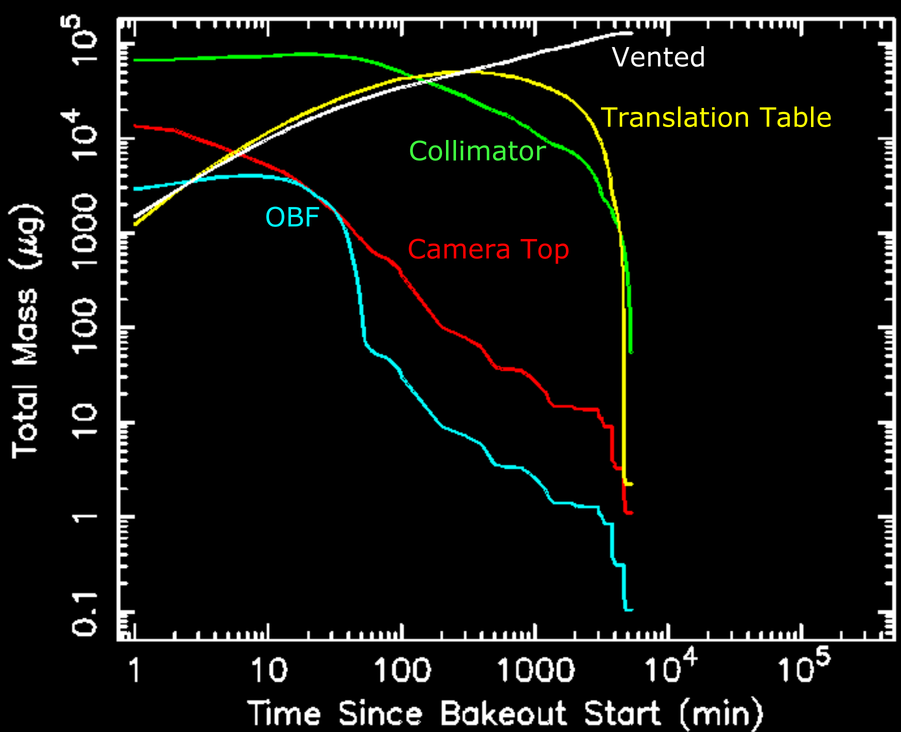
Vaporization rate: Dependence upon phase state



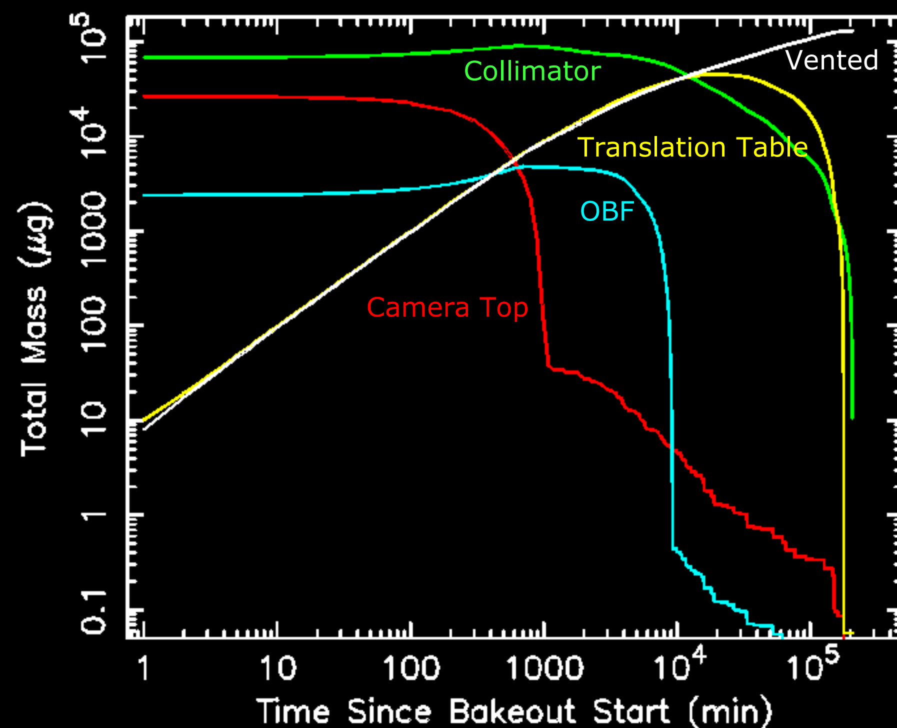
Contaminant mass
Cool bake-out

T_{FP} = -60°C T_{DH} = +25°C T_{OBF} = +10°C T_{TT} = -10°C

- Octadecane



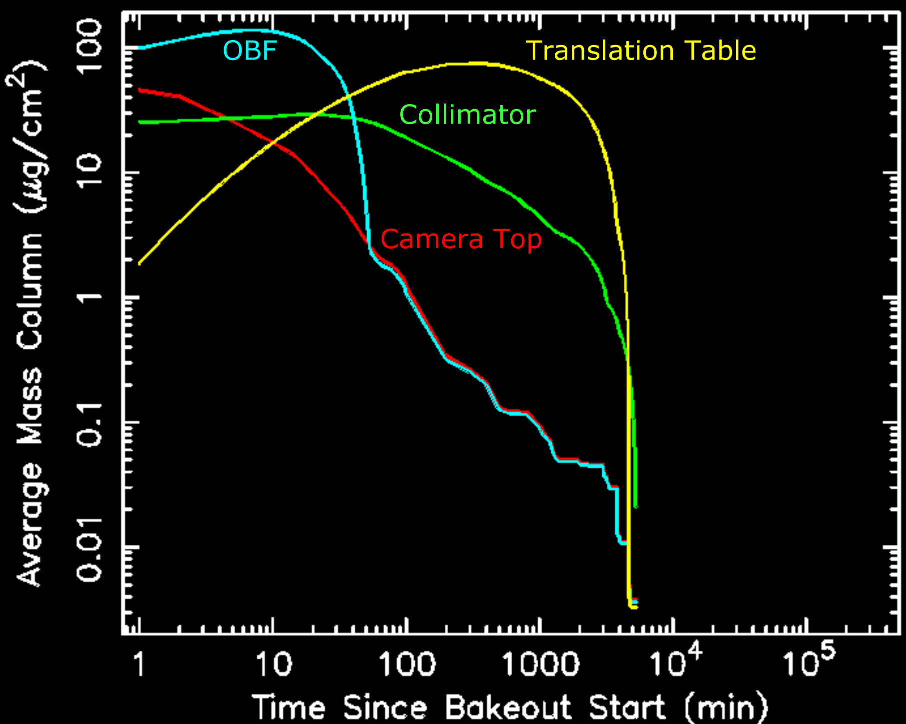
- Dioctyl phthalate (DOP)



Contaminant mass column
Cool bake-out

T_{FP} = -60°C T_{DH} = +25°C T_{OBF} = +10°C T_{TT} = -10°C

- Octadecane



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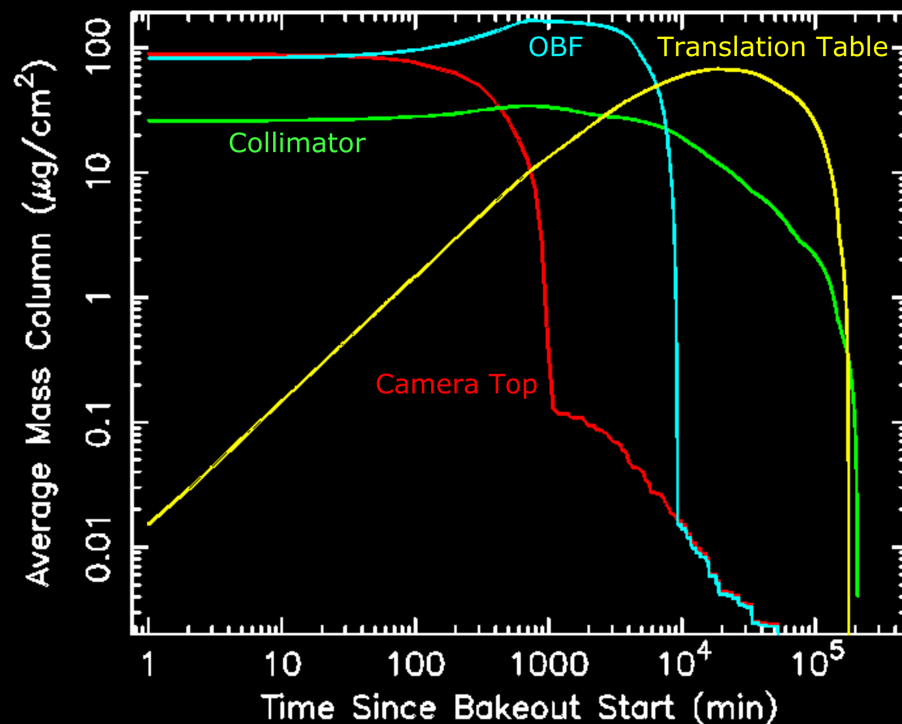
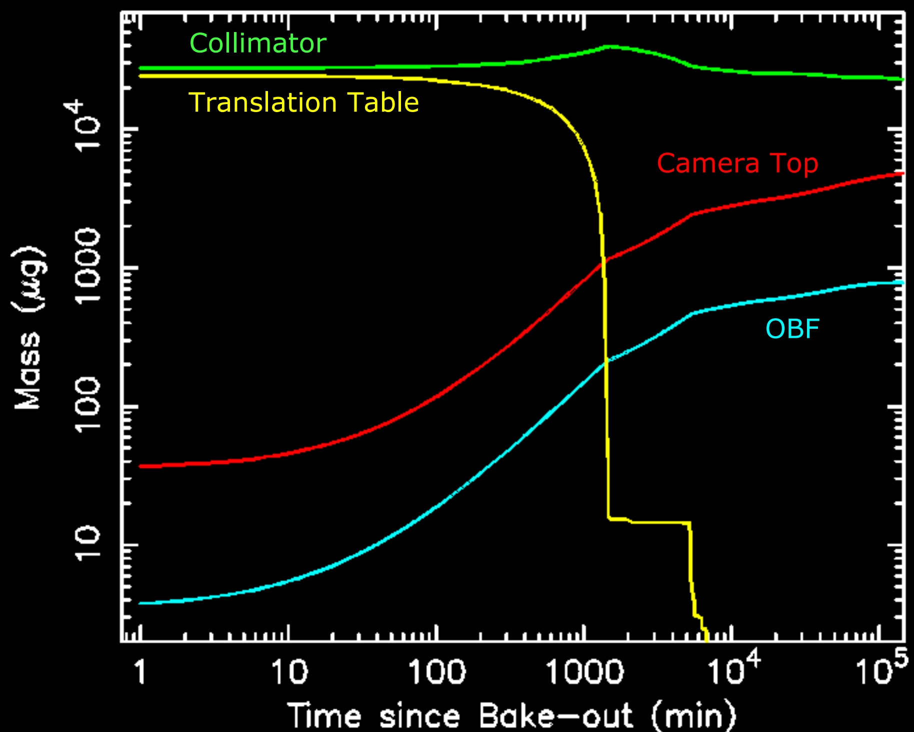


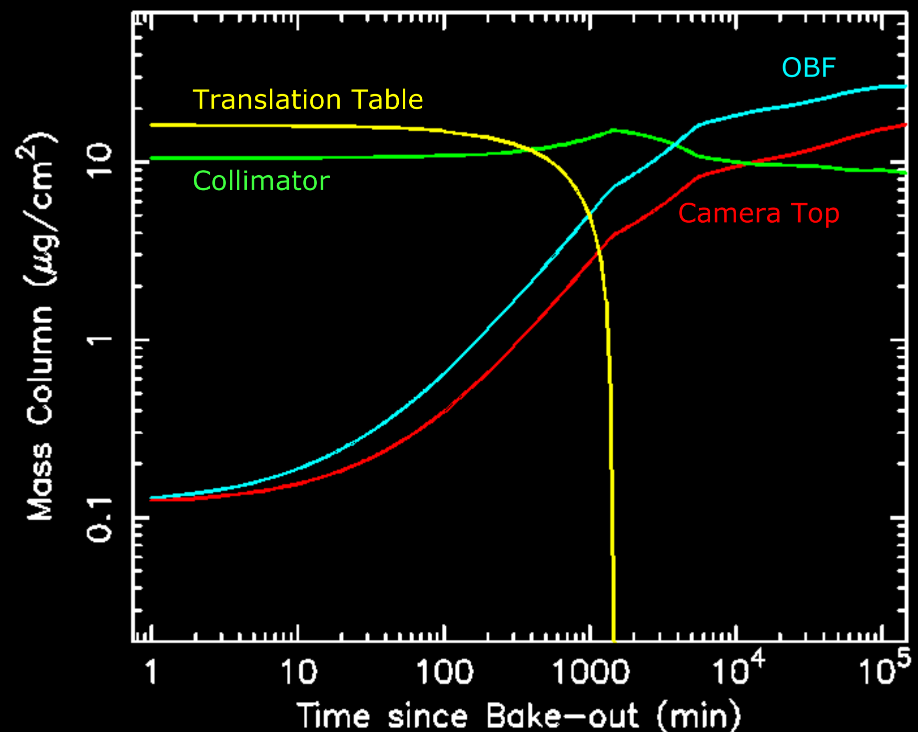
Contaminant re-deposition after (partial) cool bake-out

Octadecane/10

- Mass



- Mass column



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Summary

- Contamination-migration simulation provides a useful tool
  - Utility for absolute predictions is still limited
    - Absolute predictions require knowledge of contaminant’s volatility
    - Uncertainty in temperatures propagates exponentially to rate error
  - Model may require additional physics
    - Treatment of multiple molecular species is not simple superposition
    - Dependence of thermal emissivity upon contaminant mass column
    - Surface redistribution, especially for a liquid contaminant
- Chandra Team has again deferred a decision to bake-out
  - Scientific productivity continues despite low-energy absorption
    - Observing proposals remain oversubscribed by factor ≈ 5.5
    - Over 400 refereed papers per year, steady over past decade
  - Identified risks of performing bake-out are small but not zero
  - Bake-out might not substantially reduce contamination on OBFs